Poultry manure management: Environmentally sound options

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ABSTRACT: Increases in the demand for poultry products have led to rapid and concentrated growth of the industry, which has caused excessive manure supplies in certain areas. Although poultry litter is one of the best organic fertilizers available, and is an extremely valuable resource, excessive land application rates can lead to nitrate leaching into groundwater, phosphorus (P) runoff into adjacent water bodies, and possibly cause elevated bacterial or viral pathogen levels in lakes and rivers. Approximately 13 million Mg (14 million tons) of litter and manure was produced on U.S. poultry farms in 1990, most of which (68%) was broiler litter. Except for small amounts used in animal feed, the major portion (>90%) of poultry litter produced is applied to agricultural land. Adverse impacts resulting from land application of poultry manure may be prevented by implementation of effective best management practices (BMPs). Examples of BMPs include proper nutrient management using agronomic rates of N and/or P, use of buffer zones between treated areas and waterways, correct timing and placement of manure, and irrigation scheduling of liquid manure to limit groundwater contamination. Nutrient loading rates should be based on P in areas of the country that have P sensitive waterbodies and on N in areas where eutrophication of surface water is not a problem. These practices manipulate the soil system to minimize pollutant loss to surface or groundwater. Future research needs include the development of new BMPs that result in decreased negative environmental impact from land applications of this important resource.

Increases in poultry production in recent years, driven by the demand for low-cholesterol meat, have led to tremendous expansion in the industry. Rapid and concentrated growth of the poultry industry in several states, however, increased the concern about disposing of poultry wastes with respect to non-point source pollution. Although poultry litter is one of the best organic fertilizer sources available (Wilkinson), excessive applications of litter (as with any fertilizer source) can cause environmental problems. Nitrate leaching into the groundwater, non-point source phosphorus runoff into surface water bodies, and release of pathogenic micro-organisms are three of the main problems encountered with improper management of this resource. This paper gives an overview of the current research in Arkansas, Alabama, and Oklahoma on the agricultural utilization of poultry litter, and options available to integrate litter into economically and environmentally sound management systems. Since the agronomic value of poultry litter is well known and has been thoroughly documented in numerous publications (Salter and Schollenberger; Hileman; Wilkinson; Miller et al.; Bosch and Napit), the main issues addressed in this paper are environmental, rather than agronomic.

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Manure production and composition

Integrated poultry production in the United States is concentrated in the midsouth region. Arkansas, Georgia, North Carolina, and Alabama account for more than 40% of national cash receipts derived from the sale of poultry products; Arkansas leads all states in both quantity and cash value of poultry products. As midsouth states are crucial to national poultry production, levels of poultry production are similarly important to the economic well-being of these midsouth states—cash receipts from poultry and eggs constituted 45% and 51% of total 1989 farm income for the states of Arkansas and Alabama, respectively.

Litter associated with broiler production, manure generated from laying operations (hens and pullets), and dead birds are the three wastes of primary concern in poultry production (Edwards and Daniel). Approximately 13 million Mg (14 million tons) of litter and manure was produced on U.S. poultry farms in 1990, most of which (45%) was generated in Arkansas, North Carolina, Georgia, and Alabama (Table 1). Broiler litter accounted for 68% of the total fecal wastes generated by the poultry industry in 1990 (Table 1). Although data on amounts of dead birds generated in poultry production are scarce, a 4% mortality rate over a production cycle is considered normal for most poultry operations (Edwards and Daniel). Using this value, the data in Table 1, and live weights of 0.9 kg (2 lb) bird-1 for broilers, 0.9 (300,000 tons) for layers, 0.7 (1.5 lb) for pullets, and 5.0 (11 lb) for turkeys (one-half live market weights; Sims et al., 1989), approximately 270,000 Mg (300,000 tons) of dead birds required disposal on U.S. poultry farms in 1990. Commonly used, approved methods of dead bird disposal include burial pits (open bottom), co-composting, incineration, and rendering.

Land application offers the best solution to managing the enormous amounts of manures generated on U.S. poultry farms each year. Depending on the composition of individual poultry manures, these materials can enhance crop production via their capacity to supply nutrients and increase soil quality. Broiler litter is a mixture of manure, bedding material, wasted feed, feathers, and ash (soil picked up during recovery). Bedding materials are used to absorb liquid fractions of excreta, and depending on locality, typically include wood chips, sawdust, wheat straw, peanut hulls, and rice hulls. Owing to its relatively low moisture and high macronutrient content (Table 2), broiler litter is generally considered the most valuable animal manure for fertilizer purposes. Broiler litter also contains significant amounts of secondary plant nutrients and micronutrients (Table 2). Chicken manure without bedding typically has a N content similar to broiler litter, but higher concentrations of water, P, Ca, Mg, and Zn (Table 2). It also has a higher proportion of N as ammoniacal-N (Table 2), which is subject to loss via ammonia volatilization. Turkey manure typically contains amounts of N and P similar to chicken manure, but a lesser concentration of K (Sims et al.). Dead-bird compost is similar to broiler litter in its nutrient composition, except for its lower N content; N losses are inherent to the composting process (Table 2).

Manure management systems

Poultry manure handling systems encompass operations required for the removal of manure from poultry houses, pretreatment, and transport to the field. How poultry manures are handled is dictated, in large part, by the moisture content.

A byproduct of most broiler operations

is solid poultry manure. Solid poultry manures (poultry litter and manure) contain >150 g dry matter kg^{-1}, which makes them amenable to solid waste handling systems. Removal of solid poultry manure from production houses is typically accomplished with tractor-mounted box scrapers or blades and machinery capable of scooping the material, such as front-end loaders. Currently, litter is removed after five growouts, which is once a year. Upon removal this material may be directly land applied or temporarily stored. Manure storage prior to land application, which may occur under roofed structures (dry-stack barns) or well-secured impermeable tarpaulins, allows flexibility in timing of land application. This flexibility is important for synchronizing of plant nutrient needs with nutrient release from poultry manure, which lessens the risk for environmental contamination when these materials are land-applied. Moreover, dry storage reduces the risk of environmental contamination as compared to exposed manure piles.

If stored, particularly under roofed structures, solid poultry manures may be subjected to treatments aimed at enhancing their spreading characteristics, maintaining their nutrient composition, or altering their chemical and biological properties via composting. Drying solid poultry manures at the wetter end of the spectrum, which may be accomplished via static aeration or by mixing with drier materials, may be desirable from a weight reduction and spreading perspective. Drying is particularly desirable if solid poultry manures are to be transported long distances. However, mechanical drying (fans and/or driers) of these materials is rarely practiced.

Considerable N loss owing to ammonia volatilization can occur during handling; additions of water soluble phosphate fertilizers (excluding ammonium phosphates), which react with ammonia in manures to form ammonium phosphates, have been put forward as a means to conserve N (Mitchell et al.). Additions of water soluble phosphates to solid poultry manures increases the P concentration of the manure, which may be undesirable from an environmental perspective. Additions of alum may be the best method of avoiding ammonia volatilization. This would not only decrease volatilization, but decrease P runoff as well. Recently, Moore et al., found that alum additions to poultry litter resulted in a 99% decrease in ammonia volatilization. Since there are a myriad of poultry health problems associated with high ammonia levels in chicken houses, high ventilation is often required in winter months when growers are attempting to maintain high temperatures. Treatment of the litter with alum may be a cost-effective way to maintain low atmospheric ammonia levels, high nitrogen levels in litter, while protecting the environment (decreasing P runoff).

Runoff of dissolved P from fields receiving poultry litter can occur, even when best management practices (BMPs) are utilized. This is because poultry litter contains high concentrations of water soluble P (often in excess of 2,000 mg P kg^{-1}). This fraction is readily transported in runoff water during intense rainfall events.

Recent work has shown that the level of water soluble P in litter can be reduced by several orders of magnitude with the addition of flocculating materials commonly used in wastewater treatment and lake restoration. Moore and Miller (1992) showed water soluble P levels decreased from around 2,000 mg P kg^{-1} to less than 1 mg P kg^{-1} litter with the addition of aluminum, calcium and iron compounds. In a study using rainfall simulators, Shreve et al. found P concentrations in runoff water from plots fertilized with alum-treated litter was 87% lower than plots receiving normal litter. Fescue yields were also increased with alum-treated litter, compared to normal litter, which was probably due to decreases in N loss.

Composting, which occurs naturally when non-sterile organic substrates are combined with water and oxygen, may be a desirable treatment for poultry manures. In the composting process, which may be applied to solid poultry manures and/or poultry mortalities, aerobic microbial decomposition generates sufficient heat energy to raise the temperature of compost mixtures to the thermophylic zone [40°-75°C (104°-167°F)], destroying pathogenic organisms and weed seed at temperatures ≥ 60°C (140°F). Composting reduces the volume and weight of original organic substrates, and the end result of successful composting is a material that is biologically stable, odor-free, and useful as a potting media and soil amendment. However, composting is probably not cost-effective with respect to agricultural usage of poultry manure, since it is a time consuming, costly method, resulting in an end product that is not any higher in nutrients than fresh litter.

Liquid poultry manures (those containing <150 g dry matter kg^{-1}) are generated when manure is scraped or flushed into storage reservoirs, such as tanks, detention basins, aerobic or anaerobic lagoons, and oxidation ditches. Most of the liquid poultry manure is generated in laying hen operations. While these materials are generally amenable to hydraulic pumping, those containing between 40 and 150 g dry matter kg^{-1}, referred to as slurries, can present problems to pumping equipment because of their viscosity and the potential to plug orifices. Solid-liquid separation via sedimentation or filtration may be necessary when liquid poultry manures with higher amounts of solids are to be pumped. Although storage in reservoirs often serves to enhance hydraulic properties of liquid poultry manures with regard to ease of pumping, these systems can result in considerable loss of plant nutrients. Ammonia volatilization losses from storage reservoirs range from 25 to 80% of original N contained in liquids/slurries, and P and K losses range from 5 to 50% of original P and K (Tisdale et al.).

Land application of manure

Except for small amounts of poultry manure used in animal feed, the major portion (>90%) is applied to agricultural land. This application usually occurs no more than a few miles from where it is produced. Thus, in states with a large or growing poultry production industry, increasing demands are being imposed on agricultural acreage to efficiently utilize the nutrients (primarily N and P) contained in the manure. In the major poultry producing states, the amounts of nutrients produced in manure exceed crop requirements in localized areas, especially for P. Poultry production is often concentrated in regions with small farms with very limited acreages for land disposal. While poultry production provides economic incentives for these small farmers, problems created by utilization of manure produced by these enterprises may have major environmental consequences.

Transportation. Generally, transportation of poultry litter is restricted to less than 10-20 km (6-12 mi). Obviously, being able to transport the manure greater distances from the source of production increases the acreage for land application. Assuming poultry litter contains 3.4% N and 1.7% P (dry-weight basis), a farmer would have to add five and 10 times as much poultry litter as 17-17-17 fertilizer to achieve the same N and P application rate, respectively.

Transport of solid poultry manure to the field, depending on the distance, is typically done with spreader or large-bodied trucks. Liquid poultry manures containing between 40 and 150 g dry matter

kg^{-1} (slurries), may be pumped from storage reservoirs into tank-bearing vehicles for transport to the field, which requires agitation. Liquid poultry manures having <40 g dry matter kg^{-1} may be handled in the same manner as slurries, or be pumped directly from storage reservoirs into pipeline systems, which deliver the material to irrigation equipment at the site of application.

The economics of transporting poultry litter was investigated by Bosch and Nappi. They found that in Virginia, litter transfer from areas of high poultry production to areas of low production should be economically feasible, but was not occurring. They concluded that regulations are needed that require poultry growers to have a plan for safe disposal of manure in order to operate (which would stimulate litter transfer). They also indicated that government subsidies were needed to help make litter transportation cost effective.

At present, vertical integrators prescribe most of the feed, water, medication, housing, light, heat, ventilation, and harvesting requirements for contract growers to raise poultry. Although these contracts occasionally cover certain areas of waste disposal, such as dead bird disposal, they seldom contain conditions for manure management. If the integrators were to get more involved with manure management, it would probably be much more helpful in solving any environmental problems than government regulation and/or subsidies.

Spreading equipment. The type of spreading equipment used depends on the practiced methods of storing and handling poultry manure. Traditionally, poultry manure is broadcast directly from the house, using a variety of spreaders with a shredder attachment. Manure stored in deep pits is removed by scraping and applied similarly with a spreader. In a few cases, manure stored in shallow pits is removed by flushing and, after large solids have been removed by sedimentation and/or filtration, is applied with an irrigation system. Spreading equipment can vary with contractor and has thus seen little standardization. In many locations where the poultry industry has recently expanded, existing farm equipment is used to apply the manure. There has been less progress in improving spreading equipment for solid manure than that for liquid manure.

Land base available. In most cases, the land base available for application of manure is limited. This limitation mainly arises from restrictions imposed by the economics of manure transportation as discussed earlier. This inflexibility may result in the application of manure to areas with elevated soil N and P contents from previous applications or with high runoff or leaching potentials. Consequently, recommended manure application rates should be flexible and account for differing geology, soil, and topography of potential application sites.

Currently, most manure application rates are based primarily on the management of N to minimize nitrate losses by leaching. In most cases, this has led to an increase in soil P levels in excess of crop requirements due to the generally lower ratio of N:P added in poultry manure than in crops. For example, poultry manure has an average N:P ratio of 3 (Table 2), while the N:P requirement of major grain and hay crops is 8 (Fertilizer Handbook, 1982). Because of the relatively greater accumulation of P than N in soil receiving continual application of poultry manure for several years, the soil test P level in these soils far exceeds that required for 100% sufficiency of many crops (Sims; Wood).

Basing manure applications on P, rather than N soil contents and crop requirements may mitigate the excessive build-up of soil P and at the same time lower the risk for nitrate leaching to groundwater. However, a soil test P based strategy would eliminate much of the land area with a history of continual manure applications, as many years are required to lower soil P levels, once they reach excessive levels (Wood). In addition, farmers relying on poultry manure to supply most of their crop N requirements will have to purchase commercial fertilizer N, instead of using their own manure N. Using a soil test P based strategy may resolve potential environmental issues, but places unacceptable economic burdens on farmers.

Tillage effects. Application of poultry manure before or during tillage will reduce surface soil accumulation of added N and P and increase their distribution in the root zone. If a ground cover can be maintained during times of the year when runoff producing rainfall is common, environmental risks will be reduced while crop utilization of N and P will be increased. Preliminary research in Arkansas and Oklahoma using simulated rainfall on soil receiving poultry manure indicated that soil incorporation of manure with tillage reduced N and P loss in surface and subsurface runoff compared to broadcast applications. This effect was attributed to a dilution of manure N and P in the depth of tilled soil.

Soil and manure testing. There are many variables associated with poultry management systems that can affect manure quality at the time of application. These include the type and amount of bedding material used, accumulation time, feed, amount and quality of water used to flush the house, location in a storage pit at which the manure is removed, and length of storage before land application. The variability in these management factors can result in a wide range in the nutrient composition of the manure applied (Edwards and Daniel).

In those states where manure analyses are conducted, total N, ammonium N (NH_4-N), and moisture content are generally determined. With the use of more sophisticated analytical equipment allowing multi-element analysis in soil test laboratories, total P, K, and other nutrients can also be determined and reported to the farmer upon request. As most of the N and P in poultry manure is in organic forms [>90 and 60%, respectively (Edwards and Daniel; Wood and Hall)], much of the N and P is not immediately available to plants. Manure application based on total nutrient contents are adjusted to account for nutrient availability in soil. Nitrogen availability is related to mineralization of organic N (usually 50 to 60% of the organic N fraction) and recovery of added NH_4-N. This availability may be adjusted further to account for the effect of storage time on N mineralization and volatilization and of soil type on NH_4-N fixation. It is generally assumed that 75 to 80% of added total P and all the K is plant available. A cautionary note to basing application rates on manure analyses must be sounded, because of the wide variability in nutrient contents that can be obtained. For example, variabilities associated with sampling the manure alone can be 10 to 15 g N kg^{-1} manure (25 to 35 lbs N ton^{-1}). This could amount to a 25% over or under estimation of N content (Table 2). Thus manure analyses should be used as guidelines only.

Current soil test methods represent, for the most part, plant available inorganic N and P levels in soil. Because of the high organic N and P content of manure, soil test recommendations must give credit to the mineralization of organic nutrients during the growing season. In addition, poultry manure can provide plant available N and P for several years after application. Thus, soil tests must also give credit to the residual effects of poultry manure, possibly resulting in a reduction in application rates in years following initial applications. In many instances it is difficult to develop accurate credit for the variable soil, climate and cropping conditions encountered.

Alternative uses of poultry litter

Poultry litter, when mixed with feed grains, has been found to be a successful feed for cattle. About 4.2% of the poultry litter produced in the United States is fed to cattle (Carpenter). Although disease problems have not been reported from feeding manures to animals under acceptable conditions, copper toxicity has been reported to be a problem in sheep (Fontenot et al.). The litter contained 195 mg Cu kg^{-1} due to feeding chicks high levels of copper sulfate. Currently, most poultry producers feed an excess of copper sulfate. Although this results in an increase in weight gain, the gains are not due to a change in diet per se, but rather to a change in litter composition (Johnson et al.). There are two possible explanations for this phenomenon. First, high copper levels in the litter reduced populations of pathogenic microorganisms; and second, non-biologically mediated reactions, such as ammonia volatilization, are affected.

It is important to remove any foreign materials from the litter before using it as feed. These materials include wire, plastic, and glass. It is also important to maintain a low ash content. When large quantities of soil are removed with the litter, the ash content increases dramatically. Litter with ash contents exceeding 28% should not be fed to cattle.

Composted poultry litter is also sold to nurseries and garden stores as an organic amendment. However, at present the amounts sold in this manner represent much less than 1% of the total litter produced. Poultry litter may also be use to generate electricity. A power station using poultry litter became operational in Suffolk, England, in 1992. The power plant cost approximately $35 million and will use 10,000 Mg (11,000 tons) of litter per year from the area's poultry farms.

Table 1. Number of birds and manure generated (dry basis) on U.S. farms in 1990, ranked according to total amounts of manure generated

State	Broilers		Layers*		Turkeys		Total	
	Number Produced†	Manure Generated‡	Number Produced†	Manure Generated§	Number Produced†	Manure Generated¶	Number Produced†	Manure Generated#
	Millions	kg × 10^6	Millions	kg × 10^6	Millions	kg × 10^6	Millions	kg × 10^6
Arkansas	951	1427	15.3	52.8	22.0	239.8	989	1719
North Carolina	540	810	12.5	53.4	58.0	632.2	611	1496
Georgia	855	1282	18.0	55.6	2.0	21.9	875	1359
Alabama	847	1270	9.5	34.1	#	#	856	1304
California	231	347	29.0	136.9	32.0	348.8	292	832
Mississippi	413	620	6.1	24.4	#	#	419	644
Virginia	297	445	3.4	12.1	17.0	185.3	317	643
Minnesota	41	62	10.2	41.7	46.3	504.7	98	608
Texas	338	507	14.0	50.9	#	#	352	558
Maryland	265	398	3.3	8.6	0.1	1.2	269	408
Missouri	88	132	6.6	26.0	18.0	196.2	113	354
Delaware	232	348	0.6	1.5	#	#	232	349
Pennsylvania	116	173	18.7	54.3	8.4	91.9	143	320
Oklahoma	142	213	3.7	14.8	#	#	146	228
Florida	120	179	11.2	45.1	#	#	131	224
South Carolina	84	125	5.7	20.7	5.5	60.0	95	206
Ohio	21	31	17.7	74.1	4.8	51.8	43	157
Tennessee	99	149	1.1	3.6	#	#	100	152
Iowa	9	14	8.6	33.3	8.8	95.9	27	143
West Virginia	41	62	0.7	2.0	3.9	42.0	46	105
Oregon	24	36	2.6	11.8	2.3	25.1	29	72
Washington	33	50	5.0	21.5	#	#	38	71
Michigan	1	1	5.4	18.5	4.3	46.9	10	67
Nebraska	3	4	5.1	21.8	2.1	22.9	10	49
Wisconsin	14	21	3.4	18.3	#	#	17	39
New York	2	4	3.7	12.7	0.5	5.2	7	22
Kentucky	2	2	1.7	6.0	#	#	3	8
Hawaii	2	3	0.9	4.9	#	#	3	8
Other States	156	233	47.9	182.9	47.1	513.4	251	930
Total	5966	8948	272	1044	283	3085	6520	13078

*Includes laying hens and pullets of laying age; pullets of laying age represent 56% of the total number produced.
† Adapted from USDA (1991)
‡ Broiler litter; based on 1.5 kg litter $bird^{-1}$ yr^{-1}.
§ Based on 7.00 kg manure $bird^{-1}$ $yr^{-1}$for laying hens and 1.4 kg manure $bird^{-1}$ yr^{-1} for pullets of laying age (Sims et al., 1989).
¶Based on 10.9 kg manure $bird^{-1}$ yr^{-1} (Sims et al., 1989).
Included in totals for "Other States".

Agronomic and environmental effects

Soil properties. In addition to benefits that poultry litter and manure provide to crop production in the form of nutrients, these carbon (C) bearing materials can build soil organic matter reserves, which benefits crop production via increases in soil water-holding capacity, water infiltration rates, cation exchange capacity, and structural stability. Kingery et al. showed that litter applications resulted in increased organic C and total N to depths of 15 and 30 cm (6 and 12 in), respectively. Litter improves the water holding capacity of soils, as well as infiltration. Soil tilth is also improved by increasing organic matter contents by applying litter.

Metals, such as arsenic (As), copper (Cu), and zinc (Zn), are often fed to poultry. This results in average concentrations in the litter of 22, 56, and 188 mg metal kg^{-1}, respectively (Table 2). Kingery et al. found elevated levels of K, Ca, Mg, Cu, and Zn in soils heavily fertilized with poultry litter. Elevated levels of heavy metals in the soil will result in increased uptake by plants, which will be consumed by animals or man. Normally, however, concentrations do not reach toxic levels. For example, Wilkinson and Stuedemann found that application of up to 68 kg Cu ha^{-1} from broiler litter resulted in only small increases in Cu contents of bermudagrass and fescue.

Soil fertility. Poultry litter is generally considered the most valuable of animal manures for use as a fertilizer, due mainly to its low water content. As mentioned earlier, poultry litter contains large amounts of N, P, K, as well as secondary, and trace elements. Under certain conditions, various salts can build up from excessive poultry litter applications. Soil salinity attributed to poultry litter applications has occasionally been shown to reduce germination and growth of corn.

Nutrient imbalances in forages due to excessive litter applications have been observed. Grass tetany in ruminants, which is related to the K/(Ca + Mg) balance in forages, appears to be more likely on soils that received excessive rates of poultry litter in the past (Wilkinson et al.), possibly due to high K levels in litter. Therefore, litter application rates should be limited to 9 Mg ha^{-1} or less for use on fescue.

Poultry litter is also a valuable amendment for rice soils that have been leveled by grading. In Arkansas, rice yields increased as much as 286% with chicken litter additions (Miller et al.). When inorganic N, P, K, S, and Zn fertilizers were

Table 2. Chemical Properties of broiler litter, chicken manure, and dead-bird compost

Component	Broiler Litter* Mean	Broiler Litter* Range	Chicken Manure* Mean	Chicken Manure* Range	Dead-bird Compost† Mean	Dead-bird Compost† Range
			g kg^{-1} material			
Water	245	220-291	657	369-770	362	217-499
Total C	376	277-414	289	224-328	232	167-270
Total N	41	17-68	46	18-72	18	13-36
NH_4-N	2.6	0.1-20	14	0.2-30	0.5	0.1-1.2
NO_3-N	0.2	0-0.7	0.4	0.03-1.5	0.1	0-0.6
P	14	8-26	21	14-34	12	7-17
K	21	13-46	21	12-32	13	8-20
Cl	12.7	-	24.5	6-60		
Ca	14	0.8-17	39	36-60	20	11-34
Mg	3.1	1.4-4.2	5	1.8-6.6	4	3-7
Na	3.3	0.7-5.3	4.2	2-7.4		
			mg kg^{-1} material			
Mn	268	175-321	304	259-378	355	205-600
Fe	842	526-1000	320	80-560	3002	807-9530
Cu	56	25-127	53	38-68	392	48-746
Zn	188	105-272	354	298-388	318	163-539
As	22	11-38	29	‡	‡	‡

* Adapted from Edwards and Daniel (1992).
† Adapted from Cummins et al. (1992).
‡ No data.

added at the same rate, these responses did not match those resulting from poultry litter. A thorough review of the fertilizer value of poultry litter and other animal manures was provided by Wilkinson.

Water quality. The customary method of poultry manure utilization is land application without incorporation, a practice that also increases the fertility of receiving areas. However, the same nutrients that make poultry manure a good fertilizer can, under some circumstances, be detrimental to the quality of groundwater and downstream surface water. The potential for water quality degradation from nutrients responsible for eutrophication (N and P), oxygen-demanding materials (organic carbon), and selected metals is of particular interest in areas such as northwest Arkansas where shallow, cherty soils and karstic geology greatly increase the interaction between surface and groundwater.

One of the primary health concerns with excessive poultry litter applications is nitrate leaching into the groundwater. The U.S. Environmental Protection Agency limits nitrate concentrations in drinking water to 10 mg NO_3-N L^{-1}. Ritter and Chirnside indicated that 32% of the water wells in Sussex County, Delaware, had high nitrate levels (>10 mg N L^{-1}) due to improper poultry litter applications. Kingery et al. found that high loading rates of poultry litter resulted in buildup of nitrate in the soil to 3 m depth or to bedrock.

From a surface water viewpoint, P is the element of primary concern, since it is generally considered to be the limiting nutrient for eutrophication (Schindler). Excessive applications of litter to soils result in a buildup of P near the soil surface. Kingery et al. observed soil test P levels as high as 225 mg P/kg soil in the soils in Sand Mountain area of Alabama.

In a similar study of continual long-term poultry litter application to 12 Oklahoma soils, Sharpley et al. (1993) found that P accumulated in the surface meter of treated soil, to a greater extent than N. This reflects the differential mobility, sorption, and plant uptake of N and P in soil.

Using kinetic and enrichment ratio approaches, the movement of P in runoff as a function of agricultural management can be predicted (Sharpley and Smith). Using these approaches, the P concentration of a 2.5 cm (1 in) runoff event of 10 kg ha^{-1} yr^{-1} soil loss was predicted for grasslands in Oklahoma. Predicted P concentrations of runoff from three soils treated with poultry litter (1.5 to 3.6 mg total P L^{-1}) were much greater than from untreated soils (0.1 to 0.2 mg total P L^{-1}. Under grass, erosion is minimal and, thus, most of the P will be transported in a bioavailable form (>80%, i.e., soluble and NaOH extractable particulate P available for algal uptake). These concentrations are two orders of magnitude greater than values associated with eutrophication (0.01 and 0.02 mg P L^{-1} soluble and total P). The potential increase in P transport in runoff highlights the need for careful management to avoid surface soil accumulations of P as a result of poultry litter applications on soil susceptible to runoff and erosion.

Poultry wastes are known to contain many potential pathogens. In Arkansas, the nation's leading poultry producing state, 90% of the surface water bodies (statewide) sampled by the Arkansas Department of Pollution Control and Ecology contained fecal coliform counts in excess of the primary contact standards. However, fecal coliform counts prior to the rise in poultry in this state are not available. Therefore, it is unknown whether these levels are indigenous or, in fact, due to runoff from animal manures. Giddens and Barnett indicated that moderate amounts of surface-applied poultry litter should not cause a water quality problem (with respect to bacterial contamination) unless excessive amounts of rainfall occur.

Viruses have also been reported in poultry litter and may represent a greater problem than bacteria. These include viruses responsible for New Castle disease and Chlamydia. At present, very little information on virus runoff from fields receiving poultry litter is available.

Air quality. Odor problems are the number one complaint against animal growers received by state and federal environmental regulatory agencies. Much of the odor is caused by high levels of ammonia. Volatilization of ammonia results in decreased poultry productivity as a result of an increase in the incidence of ascites and other respiratory related maladies, such as Newcastle Disease. Ammonia volatilization also results in tremendous N losses that could otherwise be used for fertilization of pasture or cropland. Wolf et al. found that 37% of the total N applied on the surface of a pasture was lost via volatilization after only 11 days. With the inclusion of in-house losses, this figure would increase to well over 50% of the total N. Another reason ammonia volatilization is detrimental is the negative impact it has on the environment with respect to acid rain.

Crop production. Poultry litter and manure have increased yields in many different crops, such as bermudagrass, corn, fescue, orchard-grass, rice, and wheat (Edwards and Daniel; Wood). Most of the yield increases are attributed to N, however, the response in rice on graded soils that occurs in Arkansas cannot be duplicated with inorganic fertilizers.

Issues and options

Education and technology transfer. For several reasons, transfer of technology relating to nonpoint pollution, especially poultry waste management, differs markedly from production agriculture. At least initially, the state and federal agencies are involved in water quality and grower/farmer is not the target audience for new information. Within each state, a state agency is often designated as the lead agency concerning nonpoint source pollution. This is complicated by some agencies having jurisdiction for surface water but not for groundwater. In such cases, a lead agency is still identified, but one agency may take surface waters and the other groundwater. The issue is further complicated by federal agencies such as the U.S. Department of Agriculture—Natural Resources Conservation Service, which implement practices that conserve soil and water. This agency should have a major role in the decision making process because it has responsibility to design and implement the selected BMPs. The poultry processing and retailing industry is another major player because its management program is dynamic and can have a significant impact on the amount and quality of litter produced. Ultimately, the information must be disseminated to the end user or grower. The USDA Cooperative Extension Service and the NRCS, provide the critical link between the farmers and public agencies. The Extension service has primary responsibility disseminating information to farmers. The NRCS is the technical arm at the county level that incorporates the BMPs into the farm plan.

Best management practices. The concept of BMPs was introduced in Public Law 92-500, which outlined several rigorous requirements for a practice to qualify as a BMP. The practice must relate directly to water quality and it must be cost effective. This difficult and ambiguous requirement forces the establishment of a dollar value on water quality. Until better methods are developed, the process will continue to be a delicate balance between the value of the resource and cost of the practice and most likely will require consideration on a case-by-case basis. Acceptability and economic returns to the grower are other requirements. Without them, volunteer adoption will be low. Generally, practices that increase net income are compatible with water quality; however, accomplishing this requires a higher level of management by the grower as well as the NRCS technician developing and implementing the farm plan.

Adverse impacts resulting from land application of poultry manure may be prevented by implementing effective BMPs. The most effective BMP is limiting land application rates to those needed for nutrient utilization. Examples of other BMPs include using buffer zones between treated areas and waterways, applying the litter when rainfall is less likely in the near future, and light incorporation where soil, topography, and cropping system permit. Litter amendments, such as alum treatment of litter, may also be effective BMPs since they result in less N loss and a decrease in P runoff (Moore and Miller 1994; Shreve et al.).

Best management practices are available now that will protect and maintain water quality, others are in the process of being developed and field tested. Some of these practices were initially used for erosion control and have been around for some time. Others are new and were designed specifically for protecting water quality. Generally there are three categories for classifying BMPs that address water quality problems associated with animal wastes. These include structure control, source control and land management.

Structure and source control. Practices that fall into this category are those that limit pollutant transport through water management. Examples include terraces, grass waterways, buffer strips, manure storage facilities, dead bird composters, sediment catch basins, and so forth. These practices have a proven record of effectiveness. Buffer zones installed below cattle feedlots, for example, have proven effective in reducing transport of both N and P.

These practices are very effective, easy to manage, and include practices that focus on controlling the problem at the source rather than after entry into the aquatic system. Example practices include limiting manure application rates, application of manure only on certain slopes, and time of year.

Moving poultry litter to areas where soil N and P levels are low would not only improve crop production, but would decrease the likelihood of environmental problems associated with excess litter. However, the cost of transportation would prohibit this practice, unless the government or the industry provides subsidies for such a program as indicated by Bosch and Nappit.

Land management. Some practices manipulate the soil system to minimize pollutant loss to surface water or groundwater. Some of these practices include timing and placement of manure, application method (broadcast versus incorporation), nutrient management, and irrigation scheduling of liquid manure to limit groundwater contamination. Runoff losses of soluble P are affected by land application of commercial fertilizer and animal manure and the amount lost in the runoff is directly related to how the materials are managed. These losses are often linearly related to application rate with greatest losses of P occurring when the fertilizer or manure is broadcast and not incorporated. The level of soil test P also influences the concentration and eventual loss of soluble P in runoff (Sharpley et al. 1981).

Needs

Historically, strategies for land application of animal manures have been based on meeting the N needs of the crop being produced. Perhaps this approach can be justified on the basis of groundwater protection but little can be gleaned on the basis of surface water protection. Therefore, the question as to whether poultry litter applications should be based on P loading, rather than N loading, has arisen.

Use of critical soil test P levels should be applied at a watershed level rather than at the farm level because P losses are rarely uniformly distributed within a watershed (i.e., critical P contributing areas exist as a result of land use and natural processes). In addition, the watershed is the logical unit for correlating land use with the impacted water body. To aid in developing a cause and effect relationship, runoff models need to be refined to better account for P losses from various land-use scenarios. The traditional methods of analysis for P in the soil should be reviewed in light of the move to sustainable agriculture and conservation tillage. Under these systems and where land application of manure is practiced, the pool of soil P appears to be changing and this may not be reflected by the traditional soil test. In some cases, soil test results may suggest the addition of P without a possibility of P response due to crop needs being met by mineralization of organic P.

From a water quality standpoint, methods for analyzing runoff are needed that determine the amount of algal available P in soluble and adsorbed form. Methods such as those recently outlined by Sharpley et al. (1991) that identified bioavailable P (BAP) should undergo wider testing by researchers and appropriate agencies. Additionally, some method of relating soil test P to water quality is required. Investigations that examine the relationship between quick tests for soil, labile, and algal available P should be encouraged.

Although many models are available, it is often difficult to select the most appropriate model to obtain the level of detail of information required. Once the appropriate model is chosen, a major limitation is often the lack of input data to drive the model. This most frequently limits model use, and output will only be as reliable as data input. Because of these limitations, more research should be directed to developing a soil index to identify soil and management practices that may enrich the bioavailable P content of surface waters.

Research on P precipitation in manure utilizing Al, Ca, and Fe compounds, as mentioned earlier, is warranted. If an economically feasible treatment method is found that transforms phosphate in poultry litter to an insoluble mineral that is stable for geological time periods, then application rates of litter could be based upon N loading. Efforts should be made to utilize compounds that minimize ammonia volatilization, hence, conserving N and decreasing the threat of acid rain.

Runoff studies focusing on movement of micro-organisms from land applied poultry litter into adjacent water bodies have not been reported in the literature. Information is needed on the types and amounts of organisms reaching water bodies from land application of poultry manures and on BMPs to deter such movement. Nutrient management studies should also be conducted to determine BMPs that minimize groundwater contamination from nitrate from poultry litter.

Recommendations

- Studies are needed to determine whether poultry litter application should be based on nitrogen or phosphorus loading.
- Critical soil test P levels that lead to eutrophication of sensitive water bodies must be identified.
- A need exists for a soil test that relates P levels in the soil to P runoff from fields.
- Research on P precipitation in poultry litter using Al, Ca, and Fe amendments should be continued. Efforts should utilize compounds that inhibit ammonia volatilization.
- Studies on N dynamics and leaching, particularly nitrate leaching into groundwater, are needed.
- More information is needed on the loss of micro-organisms, particularly pathogens, in runoff from pastures receiving poultry litter.
- Models that accurately describe the fate of nutrients (particularly N and P) in poultry manure, soil, and water should be developed.

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